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ENROUTE SECTOR REDESIGN
(FIELD SURVEY OF FLIGHT STRIP DATA)

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16. Abstract

A flight data survey has been conducted at eight air route traffic control centers to identify sector flight data requirements when operating with National Airspace System Stage A radar data processing (RDP). Controllers stated which flight data elements, presently shown on paper flight strips, are required for continuous display when using RDP, and which elements can be deleted from display or placed on a callup status in a redesigned enroute sector. The results of this survey and a concomitant analysis of hand annotation of control information on the strips are intended to guide design of a testable and improved display that can replace the paper strips. Procedures to be followed in demonstrating the potential utility of such a reformatted and automated display of flight data are summarized. Also, tests to be conducted with improved data input facilities are described.

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FOREWORD

The Human Engineering and System Test Branches at the National Aviation Facilities Experimental Center (NAFEC) have been assigned enroute sector redesign responsibilities under subprogram 122-112. Following an initial phase of human engineering analysis of the sector display and data entry interface, it was decided that the greatest immediate opportunity for improvement of sector productivity was the substitution of an electronic display for the printing and handling of flight progress strips. Since the Mitre Corporation had been engaged in field study of flight data handling, the Systems Research and Development Service requested the formation of a joint NAFEC-Mitre team to plan and conduct a survey of the utilization of flight data in the digitized radar system which was then becoming operational across the nation. The Mitre Corporation will report separately on the resulting activity.

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INTRODUCTION

PURPOSE.

The purpose of this survey was to provide information on the actual workings of the National Airspace System (NAS) A3d2 enroute air traffic control system with special attention to the requirements for flight information that is presently displayed on flight progress strips. The results are intended to guide a planned test and evaluation activity directed toward development of improved display of flight data in an improved sector design.

BACKGROUND.

This activity is a continuation of the development effort that has been conducted by the Federal Aviation Administration (FAA) and its predecessor agencies since the beginning of a national air traffic control (ATC) system in 1937. It is a fact that the ATC system is changing more dramatically at the present time than ever before. Stage A of the NAS, the enroute portion, and the automated radar terminal system (ARTS) are coming into simultaneous operation at 20 air route traffic control centers (ARTCC's) and at 61 airports. Before describing the present efforts at redesign of the enroute sector for the upgraded third generation system, the developments up to the present will be outlined to indicate the place of flight strip information in ATC.

The first ATC system kept track of airline traffic by moving identified wooden blocks across a table map as pilots reported passing over radio-beacon checkpoints or fixes. The flight progress strip was evolved as a way of tabulating a series of flights that would pass over a particular fix. Having as its main elements the aircraft identity, route of flight, estimated and reported times of attaining fixes along the route of flight, and aircraft altitude, the strip displayed to the air traffic control specialist (ATCS) the data needed to determine control actions. The ATCS could note the minutes apart in train or the differences in altitude between aircraft heading for a fix and apply the aircraft separation minima that were required by regulation. This first-generation ATC system conventionally is called manual control.

After approximately 10 years of gradual expansion of the zone of control and of ground-to-air radio coverage, this first-generation system was replaced, again by gradual increments, by a radar surveillance system that permitted the ATCS to see a map-type display of the instantaneously updated aircraft locations. Because radar coverage is never total, some aircraft continued to be followed by the earlier position-reporting system, e.g., by arrangement of flight progress strips, by estimated time of arrival at a fix. Hence, the radar or second-generation ATC system was actually a hybrid of radar control and manual control. Furthermore, to serve as a backup if radar failed and to provide an immediate record for the convenience of the ATCS and a more permanent record of system actions, each enroute sector handling a flight prepared and displayed at least one strip per flight. For a complicated route of flight, a given flight might have several strips prepared for multiple posting under each of the main fixes that it would overfly in the sector.

The second-generation system was about 25 years old when the nearly simultaneous national implementation of NAS and ARTS began. Of course, automatic data processing with storage of flight plans and automatic printing of flight strips on stored plans, plus a degree of exchange of information between computers, had been added to the second-generation system at the highest density locations. In that sense, semiautomatic elements had come into the system before the third generation, but NAS and ARTS constituted a quantum jump forward in semiautomation. Larger digital computers provided improvements in the situation displays, tagged data blocks to the targets, and expanded the storage, printout, and interfacility exchange of flight plan information to a national network. This NAS-ARTS, or third-generation system, has been procured and installed in a much shorter time period than that required to spread the first-or second-generation systems across the nation. The enroute portion, to which this activity is addressed, is in place in all centers, although some ARTCC's are still in the process of making necessary adjustments and local adaptations, while others are fully operational. The move from initial NAS system integration, through shakedown, to fully operational status is an evolutionary process with successive models of computer programs and with two major phases, called flight data processing (FDP) and radar data processing (RDP). The evolutionary process is conducted with the programs for FDP coming first while the new NAS plan view displays (PVD's) continue as in the second-generation system to display radar data. This radar data is usually referred to as broadband display to distinguish it from the computer-processed digital display that comes into being with RDP.

While the NAS-ARTS computers and displays were procured and installed in a brief time span as indicated above, the third-generation system had to continue to use the same network of radars that had served the second generation. Now that the facilities have been installed to utilize digital radar through RDP in the enroute system, additional radars will be added to the network at lower cost, only narrowband transmission facilities being required, in contrast to the very expensive microwave relays required for broadband radar. But in the meantime, the third-generation system operates as a hybrid of radar control and manual control, significant areas of the over-ocean zones and of terrain-masked land areas not being covered by radar surveillance. Hence, the flight strip has been retained with essentially the same use. All sectors receive printed flight strips on computer-stored flights, which constitute the vast majority of instrument flight rule (IFR) traffic. Furthermore, the printed strips are distributed to the sectors in advance of the time flights enter the sector thus providing a valuable aid in planning control decisions. Despite these advances, there is still a great deal of manual processing in manual control. The parallel updating, sequencing, and removing of strips maintained on flights under radar control is accomplished much as in earlier systems. This manual processing has several advantages for the system that should not be overlooked. Since some flights in every ARTCC area of responsibility may have to be controlled manually, it is generally thought that ATCS's retain a degree of proficiency in exercising control without radar surveillance such that a manual backup system exists as a protection against catastrophic system failure, as for example, in an electrical casualty. It is

intended to return to this point when discussing the results of the initial survey, but here the emphasis is on the potential for the ATC system to continue to function in a backup mode because of the retention of the flight progress strip. Another advantage of the manual handling of the strip is the ability of the two or more ATCS forming the crew of a sector to communicate with each other and to record events. For example, the ATCS has a repertoire of hand notations and symbols that he writes on the strip. Such a notation tells the adjoining controller that an action has been taken and makes up a record of flight handling that can be examined later should the need arise. Another convenient communication process that occurs is noted when an ATCS reaches over and moves one or more strip holders to project out slightly from the usual resting notch. This calls attention to a needed action and leaves a ready reminder for another member of the team when he is free to attend.

Having pointed to the utility and convenience of the flight progress strip, it is necessary to recognize also the costs of retaining paper strips in a semiautomated system. First, there is the flight strip printer, a complex computer-controlled device that requires repair. Then there is the computer time required to feed an array of flight strip printers located among the sectors. Since individual flight and sector requirements vary, the program generally calls for printing of more separate strips than the minimum required by the ATCS at any given location; hence there are many strips that go direct from the printer to the waste basket. In the restrained ambient light of a control room, reading red and black characters and numerals printed on the paper strips is difficult. Hence, the strips have to be large to accommodate large print, thereby requiring considerable space in the sector for display of an array of strips. The reading problem may produce a requirement for supplemental lighting. Taken together with the manual-handling requirements, costs of using paper strips are considerable in magnitude. This area became, then, a prime candidate for study in the sector redesign activity.

A major improvement in the productivity and efficiency of the enroute sector may be attained if the "D" controller can be freed of the manual handling of paper strips. If this is done, his console can be redesigned to permit him to assist the radar controller to a greater extent. Achieving this greater support of the "R" controller would reduce the need for a "third man," variously called a tracker or handoff assistant, squeezed between the "R" and "D" controllers. Space is too tight for comfortable operations with three men in the six front feet provided by the two, 3-foot consoles. Also, it will be noted that two controllers assisting the radar controller get considerably less than twice as much productive work accomplished as would one assistant because of the added coordination. If we were dealing with a simple production task in which each person could work independently, the more men, the more work would be accomplished. A sector does not function that way, however. Here we have the "R" controller on the radiofrequency passing control decisions to the pilot. The more persons who have to process that same information or related information the more processing workload. Hence, the leverage for improving sector functions seems to exist in the potential

worksaving in handling flight progress strips. If an automated display can be introduced, this manual labor can be reduced while a more legible reading surface is provided. This is the basic reason for priority study of an electronic tabular display as a replacement for the traditional arrangement of flight data.

Before initiating an experimental program aimed at finding answers to "how to design an improved sector," it was necessary to formulate determinate questions for test. It would be inefficient to try all the possible ways of reformatting flight information on all possible candidate displays. Rather, information is needed as to the minimum flight data that is necessary for continuous display at the sector. The NAS system already provides in the computer readout display and associated controller input keyboards the capability to callout selectively required information that is stored in the computer. A second major question to be answered before starting experimentation concerns the interactions with the displayed flight data that the ATCS must be able to initiate. Should a computer-driven tabular display of some kind be considered as a replacement for the columns of paper flight strips at the sector today, it would be unfeasible to provide for the full repertoire of symbols and revisions that are allowed today by the combination of handwriting and paper. Beyond these two key questions of the minimum data for constant display and the minimum of essential display revision flexibility, there are several broad system questions needing at least preliminary answers before test planning can be effective. These questions have to do with the actual control practices in the NAS system, division of duties between team members, and planned modes of continuing operations in particular types of failures.

The remainder of this report summarizes the field survey activities that have been conducted to answer the preliminary questions and lead up to initial laboratory testing. An outline of the method of conducting the survey is followed by a synthesis of the composite results. Finally, these results are focused on the plans for an initial demonstration of a reformatted and simplified display of flight data and the remaining test questions relating to controller input of control information on the electronic display.

DISCUSSION

METHOD.

The field survey was conducted by a combined Systems Research and Development Service (SRDS), Mitre Corp., and NAFEC team. The team members included systems test, ATCS, computer systems, and human engineering specialists.

Preliminary data collection forms were constructed based on a list of all the items of information that were thought to be needed. These forms were in the pattern of a structured interview guide for the tabulation of inputs from the

data systems officer (DSO) at each center and open-answer questionnaires for completion by an area officer at each center. Checklists and short-answer forms were chosen for the ATCS in the sample.

The preliminary forms were used in an initial data collection attempt at the Jacksonville ARTCC. Following that experience the data forms were revised and duplicated for use in the main series of center visits.

Centers to be visited were selected to encompass a diversity of operational environments: centers with a heavy concentration of traffic originating and departing from a few terminals, versus centers with a greater mix of overflights and military missions; centers with mountainous terrain and the radar coverage problems caused by those obstructions versus centers with more complete surveillance; and centers with relatively more experience in radar data processing with NAS as opposed to others that started later with the new system. In the order in which they were visited, the centers included were: Kansas City, Cleveland, Los Angeles, Oakland, Jacksonville, New York, Denver, and Boston.

Generally, the survey plans were coordinated through Air Traffic Service in the Washington headquarters, and the selection of centers was approved by the respective regional offices. When requested, a background briefing was given at the regional office and repeated at the center. Copies of the survey forms had been sent to the centers prior to the arrival of the survey team, and telephone contact had been made with supervisory personnel to explain the scope of the survey and to request that particular center personnel be designated in advance to participate by contributing their responses to the survey forms and by joining in discussions with the survey team.

With the preparations outlined above, the team was able to meet with the selected air traffic controllers on the morning of the first day of the center visit. As requested in the advance contacts, each center had designated from four to six of the most experienced and knowledgeable journeymen as participants. Others joining in the discussions often included the DSO and an area officer plus as many as three other senior staff members. The relatively small number of controllers requested to participate in the survey reflected the desire to minimize conflict with center operations. Also, it seemed that this survey could best be conducted with a small number of participants since a wide variety of points was to be explored, and it was desired to followup the answers with in-depth discussion of the kind that is not productive with a large group. The briefing and discussion of automation experience to date finished up with instructions for completing the survey forms. Each controller was asked to state the sector with which he was most experienced and to describe the traffic and unique features of that sector. After each man had outlined his "favorite" sector, an agreement was reached as to the point of view to be adopted by each controller in formulating survey answers. It was usual to engage in some "horse-trading" to get each man aligned with a sector and a choice of position, "R" controller or "D" controller, that seemed to present the best mix among the respondents to sample the various typical situations of the particular center.

Arrangements were made to meet again on the next day for delivery of the completed forms and discussion of the answers. In the meantime survey team members visited the control room, often in company of the participating controllers, and observed particular traffic situations that had been discussed in the initial meeting. Generally, the participating controllers spent some time between the two general team meetings going over the survey forms and discussing with each other and, in some instances, with the survey team members, the answers that they were entering on the survey forms. This contributed to making the responses into consensus judgments of the participating group. We did not want unique individual experiences or viewpoints to predominate in the survey answers. Rather, the concept suggested to the participating controllers was that answers representative of the general experience and common practice at the center would be most valuable.

At the second general meeting the participating controllers handed in the completed survey forms and, in most cases, contributed a number of clarifying and amplifying points covering experience with automation to date. After covering this ground, the final meeting turned to a presentation, made by survey team members, on one concept for a tabular display of flight data that might be explored as a substitute for the display of flight progress strips. Thus, the participants were left with some novel ideas that would give them a picture of the sort of laboratory testing that was then envisaged as a next step in using the information that they had provided toward the larger goal of sector redesign and improvement.

In between the first and second general meetings, two additional discussions were held, one a very brief meeting with one or more area officers, and the other a more in-depth discussion with the DSO. These meetings were conducted in a structured way guided by discussion formats that had been prepared and given to the respondents in advance for study.

RESULTS OF THE SURVEY.

There were eight areas of coverage in the interviews conducted separately with eight DSO's: current system, staffing and training, flight progress strips, flight data processing, controller workload, digital radar, radar coverage, and failures and system operational discrepancies. These areas of discussion were selected to enable us to identify major operational problems that should be considered in the redesign of ATC operating positions in the continuing era of automation implementation. Problems known to exist in the second-generation system (e.g., radar coverage) were examined with the objective of determining whether such problems were aggravated, retained, or resolved due to automation introduced to date. Post-NAS problem areas were probed to assess possible impact of additional automation functions. Finally, inquiry was made about the transition procedures that had been followed in introducing NAS stage A to obtain data of possible future aid in planning the introduction of future automation packages as parts of control sector redesign. System deficiencies believed to be temporary in nature and inadequacies for which solutions had been issued were not addressed. Similarly, matters of national or local administrative practice were not discussed.

CURRENT SYSTEM. Interviews with the DSO's at eight ARTCC's produced the following information about the enroute ATC system as it was functioning in the summer of 1974. The system in use is the NAS A3d2.0 with flight data processing (FDP) in use from 15 to 18 hours per day, the break coming late at night. Use of the radar data processing (RDP) portion of the system varied from the same hours as FDP to a minimum of zero operational use and only a few hours a day use for test and training. At six of the eight centers RDP was in use at all or a large proportion of the sectors; at two, RDP was not used for ATC operations at all. When RDP was available, the radar controller used it, often with a broadband display filling the role of an auxilliary display. The experience in changing over from broadband radar to RDP appeared to be generally favorable. Until reliability problems were reduced, ATCS's often said that they doubted their ability to control traffic using RDP. But when reliability improved, it appeared to be the case that most ATCS's quickly made the adjustment after which many said they would never go back to broadband unless the automation system failed. Some token resistance to change was reported, but these were fewer in the centers that had the most experience where expressions of pride in the joint management-ATCS success in automation implementation were reported by DSO's and confirmed by ATCS's. Four of the eight centers reported little or no trouble in maintaining continuous operations through the scheduled periods. Two other centers reported some difficulty due to failures and interruptions, and two more were in early stages of implementation before attempting to provide for operations. One center reported no system breakdowns in the preceding 30 days; the remaining seven ranged from "few" to "numerous." All breakdowns were corrected. Methods used or proposed for transition from broadband to digital radar presentation varied. Three approaches have been used successfully; all sectors transition simultaneously, all high altitude sectors at one time, and a few sectors at a time, perhaps representing a geographical area both high and low.

STAFFING AND TRAINING. Inquiry about the normal staffing of the enroute sectors produced a variety of replies. Of course, within each center there were differences between busy times and slack loads and between low-altitude sectors with complex patterns of terminal traffic and sectors with relatively simple traffic flows. Despite such intracenter differences, differences reflecting philosophy of operation were noted between centers. Minimum standard sector staffing was one radar controller ("R" man) and one manual controller ("D" man). In such a case the "D" man would move over to the flight strip printer to tear out and stuff strips needed at his sector. Thus he would combine the usual functions of an assistant controller ("A" man) and a "D" man. One center staffed each of several sectors during normal daytime loads with a single "R" man, and the DSO stated that his concept was that an ideal system would permit normal traffic to be controlled by one ATCS per sector. Standard sector staffing ranged upward from the just mentioned one- and two-man normals. A third full-time member of the sector staff was usually a man squeezed in at the PVD. He was called either a tracker or a handoff man, but in any case his function was to assist the "R" man, particularly in making computer inputs. Given either a basic two- or three-man sector staffing, several centers shared the services of an "A" man between two or more sectors.

At the other extreme, one "A" man was found serving the flight strip distribution function at one whole row of seven sectors. For the maximum traffic situation, all centers reported the practice of adding a coordinator at a busy sector or a shared coordinator at a busy pair of sectors. This controller was normally behind the "R" man and was on his feet rather than sitting. He usually had an interphone connected at the overhead console. About half the centers provided a short boom to support the interphone lead and keep it from drooping near the backs of the men at the PVD. One center reported that virtually all ATCS's were qualified at "R" or "D" positions; hence, they did not staff any "A" positions. Thus the full range of staffing would be from one, always an "R" man if it were a sector with a broadband or digital radar display, to five, an "R" man, a handoff man, a "D" man, an "A" man or trainee, and a coordinator.

A highly variable factor was the actual presence of developmental controllers functioning as "A" men. DSO's acknowledged that a full analysis of controller/sector workload remains to be accomplished taking account of the impact of automation.

With the present relative stability of traffic count, it was reported that after more experience with RDP, the "R" man may be able to handle more inputs to the computer, thereby reducing the need for assistance from a tracker or handoff man. Similarly the "A" position was viewed by several DSO's as useful mainly for training in the initial stages of controller development. To make progress toward journeyman qualification, the "A" man could not remain at the printer but had to crowd in near the PVD to participate in or observe control operation. Functioning this way, the "A" man seems less a sector crewmember and more a trainee.

From the DSO reports, there can be little doubt that the introduction of automation has increased controller workload in certain activities that previously were little required. No doubt there are accompanying reductions in requirements for other activities, but this phenomenon is less striking than the increased requirement for buttonpushing, for example. The changes in activity patterns present an educational problem that is being surmounted. Substantial annoyance is voiced when the added training requirement is not well understood, for example in the case of differing formats for similar computer inputs from the "R" and "D" positions. But the actual problem fades in magnitude with more controller experience, though annoyance may still be voiced. Gradually dexterity in automation operation improves, and pride in proficiency causes the ATCS's to say he has little or no problem. Five of the eight centers said that supplemental staffing was still required in times of heavy traffic because of buttonpushing demands. Most DSO's said that they believed this requirement was reduced with experience. In addition to improvement with experience and dexterity, an exemplary level of ingenuity and controller capability is believed to contribute to reduction of changeover shock. As an example, several facilities reported that more of the sector planning was being shared by the "D" man during heavy traffic thereby allowing the "R" man to concentrate more on the PVD.

Maintaining a fully current, trained journeyman staff in the present period of system updates is a recognized, particular problem. Responses to this problem by the centers varied from a step-by-step recurrent training program utilizing FAA Aeronautical Center course work, regularly scheduled ARTCC classroom instruction, and simulation at the PVD, all the way to a seemingly catch-as-catch-can effort to brief the incoming shift on the latest changes. During the system's integration and shakedown phases, the centers reported conducting recurrent training with special classes on automation techniques, supplemented by system update briefings and operations review discussions. Only one center indicated that recurrent training for manual strip preparation is provided for assistant controllers on a formal basis.

FLIGHT PROGRESS STRIPS. Reduction in the total number of strips posted for each flight per sector is a stated objective at all centers covered. Most DSO's stated that most sectors can operate with one strip per flight and that this is desirable. Five centers still produce hand-prepared strips to supplement the printed strips. These manual strips often are for visual flight rule (VFR) flights or special military missions.

At most centers the "R" man makes updates on the strips covering flights currently active in the sector. He continues to do this even in heavy traffic, but four centers said that "R" men delegate part of the strip update function to the "D" man or tracker at the option of the "R" man. By observation it was noted that teams experienced in working together practiced such arrangements. Normally, the "D" man maintains the strips in sequence on the manual control boards when an update is not handled by the "R" man. "A" men are not permitted to sequence active traffic strips. The control board configuration was reported to be generally satisfactory by six DSO's. Some overflow during heavy traffic was reported at five facilities. Two centers modified the standard boards by adding an overhanging panel at horizontal PVD's.

FLIGHT DATA PROCESSING.. Six of the eight centers have in the past observed errors in the FDP, principally in automatically printed flight progress strips, or computer readout display (CRD) updates. Some such reports have been traced to human errors, such as failure to note an update, but study of a sample of used strips showed that errors do appear. Two centers reported that progress has been made in reduction of frequency of errors, and one of the two said error incidence is now so low that it does not constitute a major problem. Under certain circumstances several centers use the interphone for direct confirmation of data that is transferred through the computer. This is particularly true for information exchanged between facilities.

CONTROLLER WORKLOAD. Increased controller workload was reported by all centers as a result of two features of the NAS system. All agreed that the radar controller has to make more machine entries by pushing buttons than he did in the earlier system, and this of course is the major reason that a second controller is squeezed in front of the PVD in certain heavy-load conditions. With heavy traffic, the "R" man needs to keep his attention on the radar display much of the time. Normally he looks away to refer to the strips and to the CRD, but

many of these glances are accomplished in less than 5 seconds each, allowing a quick return of focus to the main PVD picture. Data inputs to the computer, in contrast, may require considerably more than 5 seconds of diverted attention, and it is this longer break in continuity of radar surveillance that increases the difficulty of functioning at the "R" position. The second workload factor cited by all centers was the difference in format between keyboard entries made from the "R" and "D" positions. Since the men interchange between the positions, the difference in format tends to produce habit interference until the accomplishment of a degree of overlearning. When the functions required by the system have been more recently learned, the workload increment is noticeable.

Additional responses from the DSO's indicated that a number of NAS change proposals (NCP's) have been initiated to remedy specific workload-producing items. It is expected that in the course of time such NCP's and program updates will resolve the bulk of specific complaints about problems with particular ATC precedures.

DIGITAL RADAR/RADAR COVERAGE. Since RDP is closed down late at night, at least one transition a day to broadband is required, plus the corresponding transition back to digital in the morning. Additional transitions occur in the case of threatened thunderstorms or system casualties. Five of the six centers that are using RDP for active control sectors reported that the transition to broadband created problems. Problems included beacon code assignments, identification or reidentification, and beacon code allocations. Incomplete radar coverage was cited as a particular problem at five centers. At the three centers not complaining about coverage, target splits and holes in radar coverage were mentioned. Properties of the digital radar presentation were reported to reduce the value of the information to the controllers, the narrowband weather being particularly mentioned.

FAILURES AND OPERATIONAL DISCREPANCIES. A wide difference was reported in the maximum time that the automation system had been down due to a failure. One DSO said recent experience showed no significant periods of failure. Two centers were not far enough along in shakedown to provide meaningful data. Another center replied 20 minutes, two said 30 minutes, and two said either 2 or 2 1/2 hours. Outages such as the last resulted from serious electrical problems in main computer systems, e.g., two storage elements out at once. All centers reported that they were using audible alarms for certain failures. Usually the alarm was to alert the controller to a failure in the display channel. Seven of the DSO's said that they were satisfied with the system failure and recovery procedures as used at the facility. However, this satisfaction did not extend to the commercial power supply. Recognition was shown of the need for a truly uninterruptable power supply allowing continued automation system operation in thunderstorms. At present, several centers find it necessary to make planned shutdowns that require 15 minutes computer outage. Not wanting to go through another 15 minutes outage in a startup during busy traffic periods, the system may remain on broadband radar for some hours until a changeover to commercial power during the regular night automation shutdown.

When asked for the greatest weakness of automation, excepting reliability, the DSO's concentrated answers in two areas: problems associated with obtaining timely corrections and problems associated with controller workload and update training. The complaints said to be most often heard from controllers were, again, the turnaround time in obtaining response to a controller-identified problem and the workload-producing features of automation, button-pushing, and reliability of equipment. Radar coverage limitations were mentioned, and added discussion with ATCS's reveals that the controllers are keenly aware of deficiencies of radar inputs. Sometimes radar splits and ringaround are referred to as though they were automation problems, suggesting perhaps that these system defects are in the forefront of controller thinking. Track swaps have been observed at all centers, but the DSO's indicate that reports of swaps between discrete beacons are generally not confirmed. Beacon-primary, and nondiscrete versus another nondiscrete swaps do occur under certain conditions. Problems in accomplishing automatic handoffs between sectors arise when the aircraft is moving from one altitude zone to another, just as they do in intercenter handoffs, because the program is not altitude sensitive. Within the centers, the majority of DSO's indicated that procedures in use were satisfactory for accomplishing altitude change sector handoffs. Seven DSO's said that lost data had been reported, usually in computer readout display updates. This was said to be rare and in some instances to represent a failure of the controller to take timely notice of displayed information. Five DSO's reported that one or more incidents had occurred that were attributed to automation operations. Perhaps a typical case was a track hanging up on a ground return so that the aircraft passed on to proximity with another track while the "R" man thought large separations still existed. Such events were reported to be rare. All DSO's agreed that the "D" position should have added radar input capabilities that would allow the "D" man to give more aid to the "R" position. Similarly, there was unanimity in one added area, all DSO's said that glare and reflections were a problem to controllers at the PVD.

SUMMARY OF IDENTIFIED SYSTEM PROBLEMS. Taken together with the responses to the various areas discussed with the DSO's, the controller comments in questionnaire briefings highlighted a number of problems with system operations. While not necessarily related to the feasibility of an automated display to replace paper flight strips, these problems are outlined below because they appear to be of potential interest to the various activities that are concerned with system improvements and reduction of controller workload:

1. The need to operate the various input devices distracts the "R" controller. During periods of heavy traffic, this distraction is burdensome.

2. Overlapping of data blocks requires an input action to separate them so that they are legible. The automatic "unlap" feature available in ARTS is not provided.

3. Input message formats differ between the "D" and "R" positions. Basically, the flight identification is placed at the beginning of one message format and at the end of the other. Control personnel work both positions and report that the different formats make it necessary to include an extra mental process in message composition.

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4. Consoles are arranged with both right- and left-hand location of the keyboards. The left-hand arrangement is awkward for right-handed personnel. Alternating working positions with different arrangements is distracting.

5. Necessary beacon code assignment changes are not infrequent. In addition to notification to the pilot, a message must be input.

6. The "D" position cannot make all "R" position entries. There is no trackball or its equivalent.

7. The location of the "R" position input devices is difficult to reach by anyone assisting the "R" controller, as might be necessary with heavy traffic. Unlike the console arrangement known as the "island," the PVD sides are not exposed when placed side by side with other consoles. A tracker or handoff assistant must either stand behind or crowd between other sector personnel. The "R" position entry devices are inconveniently placed for an assistant.

8. The RDP system has increased the amount of information displayed on the PVD. In most cases, this information has been eliminated from some other information channel and moved to the PVD. The handoff exchange was conducted by interphone. Handoff information has moved from the audio channel to a visual one. This redistribution of information to the visual channel is reported to result in a greater need to view the PVD without the necessity of looking elsewhere.

9. When viewing the PVD, the data blocks command attention due to their size and their data content. Target position indicated by the relatively diminuitive radar symbol is less noticable. It was reported that some personnel find it necessary to make a conscious effort to confine their attention to maintaining separation of the aircraft (as indicated by the radar symbol) rather than separating the data blocks.

10. The PVD presentation was universally reported as superior to the radar bright display equipment (RBDE), but not without complaint. PVD glare and reflections are quite noticeable. Controller distraction is apparent when he notices the reflection of someone standing behind him. Separate controls for brightness of map lines, data blocks, and radar symbols were suggested.

11. All centers had some areas where radar coverage was described as inadequate. False targets, splits, ringaround, and primary clutter are experienced to one degree or another. In general, overall radar quality was noted as a limitation to achieving full benefit from RDP operation.

The foregoing problems may be regarded as falling in two categories which can be summarized:

Radar controller distraction with the need to make automation entries, and a PVD presentation weakened by glare and reflections on the viewing surface and imperfect radar data in the display channel.

General solutions to the distraction problems may, in-turn, be categorized as falling within the following improvement areas:

Additional radar controller function automation; necessary inputs shifted from the "R" controller to another operator through a combination of change to hardware, the program, and procedures; and

Simplification of remaining inputs made by the radar controller.

Improvement to the PVD presentation would be achieved by:

Optimizing the location of displayed flight data between the PVD data block, CRD, and either the strip bay or a simplified tabular display;

Improving radar quality and coverage; and

Reduction of PVD glare, reflections, and related visual stress.

RESULTS OF THE FLIGHT STRIP DATA FIELD ANALYSIS. Controllers at the eight centers completed detailed questionnaires on which they indicated the flight data elements that are required for continuous display. Since the different centers had, at the time of the survey, differing amounts of experience with RDP, there was no total consensus on all fields. Strong trends were evident in the data, however, and the material provided in questionnaire debriefing discussions helped to generate a rationale for decision on each field. When this analysis convincingly supported the requirement for continuous display, that particular field was placed in the first category. When the analysis indicated that the particular data field was unnecessary when working with RDP, that item was placed in the second category, shown below. Finally, another group of data fields produced some considerable difference of opinion, and these items were placed in a third category, to be displayed "on call" only. It is anticipated that subsequent laboratory experimentation may cause data in this third category to be reassigned to one of the other categories.

ASSIGNMENT OF DATA FIELDS TO DISPLAY CATEGORIES. The following are the assignments for continuous display, excluded from display, and available by callup:

Category I (Data to be on continuous display.)

- Aircraft identification
- Posted fix identification or departure point
- Estimated time over posted fix, or departure time, or plus time
- Assigned altitude, or requested altitude
- Arrival arrow
- Aircraft data
- Partial route

Category II (Data to be excluded from display.)

- Revision number
- Estimated groundspeed
- Sector number
- Strip request originator
- Computer identification number
- Strip number
- Previous posted fix
- Estimated time over previous posted fix
- Second ETA over posted fix
- Coordination time
- Departure arrow
- Coordination indicator
- Overflight indicator

Category III (Data to be available by callup.)

- True airspeed
- Remarks
- Mode 3/A beacon code
- Entire filed route

FLIGHT PROGRESS STRIP DATA FIELD USAGE. In the controller questionnaires each data field was reported as required either for planning or for actual control. Most respondents, however, indicated similar data usage for both planning and control, and discussion of what was meant by the two functions was not very productive. Hence, in the categorization of data fields, above, the use differences have been ignored. Data, then, is listed as required for display, not required, or needed on callup only.

It will be recalled, also, that instructions to the controllers were that they should respond in terms of a particular sector or class of sectors in the center. This instruction did not seem to influence the decision as to the requirement for display of particular data fields with one exception; this was that nonradar sectors were reported to require multiple postings when a series of fixes and computed times of arrival are used to provide the positional information in the absence of a pictorial situation display. Otherwise, the questionnaire results did not seem to be different according to special sector characteristics or different altitude strata.

REQUIREMENTS FOR CONTROLLER INPUTS ON FLIGHT STRIPS. To determine the minimum numbers of symbols that controllers require when annotating strips to record control instructions and pilot reports, a sample of strips from six centers was examined. Altogether 1,720 strips were examined. Of this number, 1,243 were found to bear one or more of the symbols described in the FAA handbook, ATP 7110.9.

The sample was assembled by first collecting one full day's production of record strips from each center. From the production of six centers, one daytime, low-altitude sector was selected at random, the minimum number of strips

in such sector bundles being 120. From two centers a second daytime, low-altitude sector was chosen, and a single high-altitude sector from one center was added. Hence, there were nine samples in all. It is recognized that any tabular system substituting for flight progress strips must have the capability to display plain language data, e.g., a notation of a special equipment outage in an aircraft, etc. The existing alphanumeric keyboard provides an input system for such notations. The special problem in going from a hand notation method to an electronic display coupled to a computer arises in the processing of unique symbols such as checkmarks, arrows, or the circling of other data. Ignoring plain language and simple number annotations, each symbol written on each of the strips in the samples was recorded. Counts of symbol frequency were made by sector, and the sectors were then averaged for an overall percentage figure on symbol utilization.

At the outset, it was noticed that the strip symbols showed certain kinds of variability. Adherence to the approved handbook symbols was generally evident, but there were considerable differences in the form of the same symbol as written by different controllers. Also, there was a wide variation in the writing instruments used: pencils in black and colors, pens of various hues, and felt tip markers. Sometimes it seemed clear that the different writing instruments were wielded by different controllers, judging from the size and form of the symbols. In other cases it appeared that a single controller used different writing tools for convenience or personal convention. Occasionally, symbols were incomplete. An altitude restriction might not be completed in full, for example. In a few cases unconventional symbols appeared to be used for emphasis. While it is not feasible to state the exact percentage of strips that had been annotated by more than one controller, the frequency of annotation by at least two controllers was sufficiently high to suggest that display equipment, intended to replace the paper strips, should have its input device placed within the reach of both the radar controller and the "D" man.

The results of the symbol counts were that 12 different symbols appeared on at least 10 percent of the strips that had handwritten annotations for at least one sector in the total sample. Five of the twelve were characters of the alphabet: A, C, D, R, and X. Another of the 12 was the data cancellation mark or dash written through a data item printed or written at an earlier time. Whether or not this dash should be considered a symbol for our present purposes is not entirely clear. Certainly, a display of flight data must make provision for deletion of obsolete information, but this might consist of simple disappearance or replacement with current information in a computer-driven display. The more significant use of the cancellation mark occurs in instances of step-by-step completion of a complex aircraft movement; for example, cancellation of transitional altitudes serves to record progress and remind the controller that a particular altitude may be released for handling of other traffic in the vicinity. In this sense, the dash would be a symbol of altitude availability, and it appears that this meaning should be provided for controller use although the particular symbol, with the delicate problem of placement on a particular data item, may be unfeasible in an automated display.

The remaining six symbols may represent a minimum symbology requirement for the level of ATC operations represented by the present sample. The six are: a checkmark, up-pointing climb arrow, down-pointing descent arrow, the arrow crossed letter "M" for maintain altitude, a circle, and an "R" in a circle. While the essentiality of the maintain altitude meaning may be debated, the simple frequency with which the six appeared in the sample would argue that the meanings behind these symbols are needed so often that the display system should provide a fast and simple method of adding an indication equivalent in meaning to each. Other less often used symbols are of great importance in the instances in which they are used, and it is not thought likely that there would not be any provision for adding the meanings that lie behind them. The frequency-of-use distinction means rather that often used meanings should be quick-action while other additions to the display might be inserted through the conventional alpha and numeric keyboards. Another approach to entry of a larger number of symbolic meanings that may be examined in laboratory tests is the "menu" list select system.

In making provision for controller-added symbols, it is suggested that letters and numbers constituting special symbols should appear with a distinctive size or other distinctive coding such as color to insure easy identification. In the forthcoming laboratory test sequence, the requirements in this area will be studied. Symbols that present particular programming problems, for example, the circle which is now placed around items of various sizes and in various data fields, may be replaced with other symbolic indicators. Color might be employed for indication of data transfer, probably radar handoff, instead of the circle. Similarly, a change in display intensity might substitute for the frequently used checkmark. Border coloring or shading might identify arrivals and departures, and use of particular display locations might indicate active, pending, arriving, departing, and holding aircraft. The goal of investigation of substitutions of this sort would be the reduction in controller workload in using and interpreting the display.

It should not be assumed that the present display of printed paper strips, with hand annotations of symbols, numbers, letters, and words, is an optimum. It may prove that there are ways to use a semiautomated display device that will give the controller a more readable display and will give him the facility to update, revise, and record the necessary ATC data with an overall improvement in workload.

The potential for workload reduction may be noted in taking advantage of the computer potential for automatic systems analysis recording of data, automatic updates, automatic resequencing of flight information displays, automatic transfer to adjacent sector displays of annotated information, and automatic display of emergency and alert indicators.

In discussion of the control symbols that are now hand annotated on strips by the controllers, it has been suggested that the three purposes of the symbols can be accomplished in other ways. We have noted these purposes to

be: aid to memory, communication with other controllers, and creation of a record that might be useful later if it were necessary to reconstruct the sequence of events. The last, or record, purpose may already be satisfied in the RDP environment. While the voice radio transmissions to the pilot are recorded, other actions of the controller are recorded through the automation system. Furthermore, these records can be reproduced with a time reference, a fact that makes them more valuable for subsequent analysis of events than a fully annotated set of strips.

An important part of the memory assistance function of strip annotations will be duplicated on the PVD by mode-C-equipped aircraft which will show the actual altitude in the data block. Similarly, the handoff status of the aircraft shown in the data block will essentially duplicate the radar contact indication provided by the letter R. In the laboratory test phase of this activity, it is expected that the need for controller inputs paralleling the present hand-annotated symbols will be the subject of inquiry. To the extent that communication within the sector team or memory reminder functions are proved to be essential, it is expected that quick-action input devices can be provided. Then for the more complex notations such as altitude restrictions either a few generic symbols may be devised, or a cuemark might be used to alert the controller that additional information is displayed in a special area or is available on call.

PLANS FOR DEMONSTRATION AND LABORATORY TEST AND EVALUATION

DESCRIPTION OF TEST EQUIPMENT.

The controller/computer interface laboratory (CCIL) was established to support human factors experimentation at NAFEC. The major projects presently active are tower flight data handling improvement, data technology, and the present project, enroute sector redesign. Figure 1 illustrates the basic mini-computer (model PDP-8) with card reader, paper tape input, disc storage, high-speed printer with keyboard, 14-inch utility display, and teletypewriter. Interface logic gives access to the computer via a touch-wire display, universal key encoder, touch-sensitive digitizer, grafpen digitizer, and a voice encoder. For the future there is the potential to communicate with the digital simulation facility that is located in the same building.

Two of the displays procured for the CCIL, as candidate devices, in the display technology activity are a Norden/Sanders color display (similar in configuration to a model PVD) and an IBM deformographic display. The deformographic is driven by a model PDP-8 and has the capacity to display about 48 full size flight progress strips or similar tabulations. A block diagram of these equipments is shown in figure 2.

Since the Norden/Sanders display is similar to a PVD, and the deformographic display is being installed in a "D" controller console, the two can be thought of as a model for an experimental enroute sector. The "D" console will have

FIGURE 1. PDP-8 MINICOMPUTER AND ASSOCIATED INTERFACE SYSTEMS

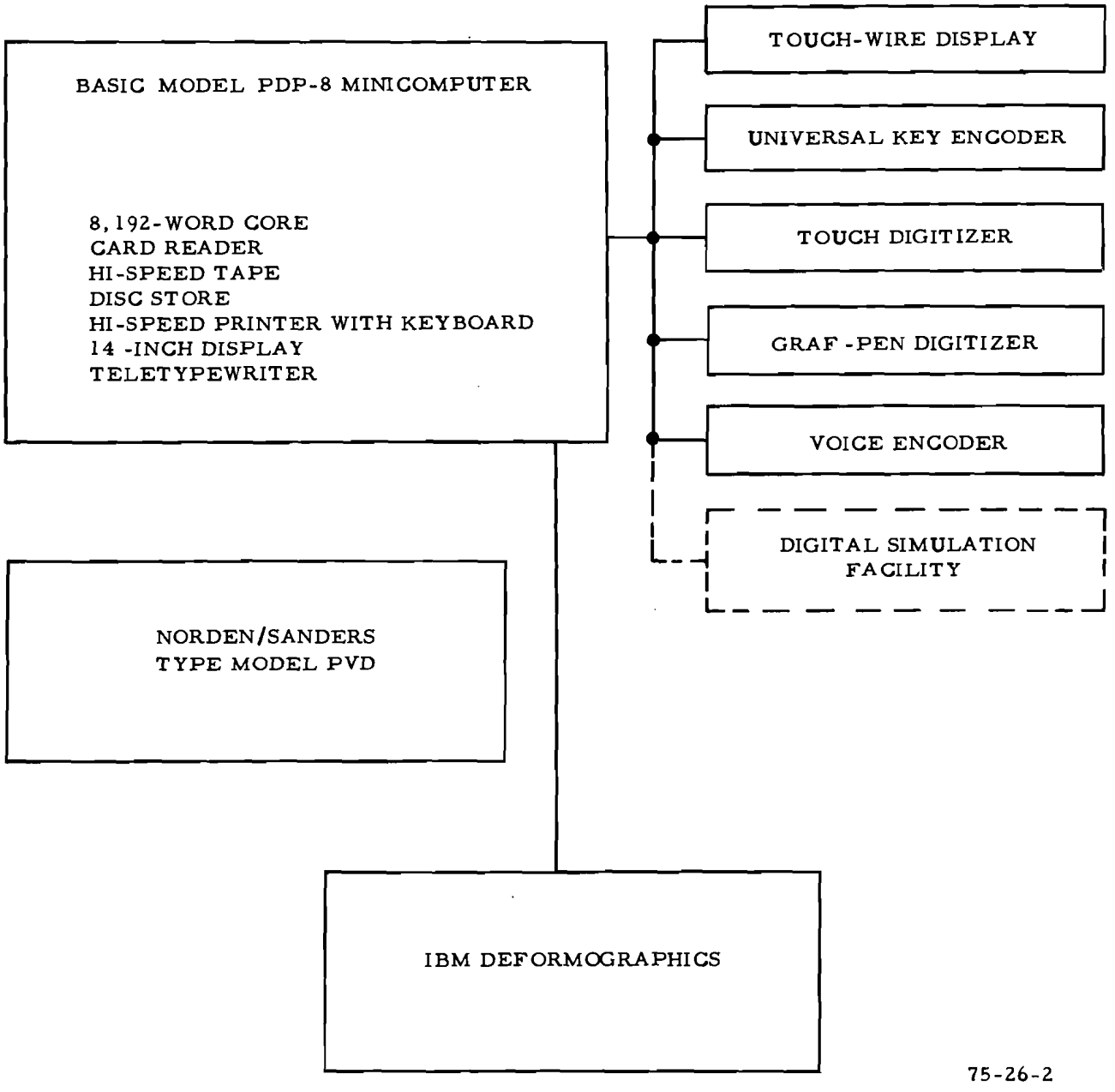

FIGURE 2. CONTROLLER/COMPUTER INTERFACE LABORATORY SYSTEM CONFIGURATION

a quick-action keyboard (QAK) and an alphanumeric keyboard (ANK) both tied to the model PDP-8. This will provide an initial controller input capability to the deformographic display. Initially, there will not be a realistic radar presentation on the Norton/Sanders display although existing taped traffic situations can be exhibited. Similarly, in the initial display demonstration phase, the deformographic will show a recorded scenario with a fixed sequence. At that stage of the activity, principal attention will be devoted to the demonstration of display capabilities. Following measurement and evaluation of the display itself, the objective will shift emphasis to the material being displayed, particularly the suitability of the simplified and reformatted flight data displayed on the deformographic. This data display will be derived from the field survey results reported above.

PROPOSED TEST PROCEDURES.

This field survey led to initial decisions as to which flight-data elements are required for continuous display, which can be deleted from the present flight-strip format, and which fields should be available on call. While some changes may be made in assignment of data fields to these categories as the result of further test and evaluation, it is clear that a degree of simplification, as compared to the present flight-strip format, is likely to be satisfactory. The first test objective, then, will be to critically examine the simplified display, starting with the items in the present "required for continuous display" category.

A recorded scenario is being prepared for this initial test of flight data simplification. It begins with display on the deformographic of a full set of sector flight strips in the present NAS A3d2 format. The second picture will show (crossed out) the fields that the survey controllers decided to delete. With those deletions made, the next stage of the display scenario will show the gaps left in the original format, suggesting the potential for simplification. Subsequent phases of the sequence will show the consolidation of the remaining items in alternative formats. Finally, the original set of sector strips will be shown in the recommended, simplified format. In making up the revised formats for the continuous display fields, there have been two guiding considerations--first, simplification, and second, preservation of conventional relationships among data fields. The latter is important to take advantage of the controllers' past experience and reduce the need for relearning.

Controllers will be asked to examine the display scenario on the deformographic system and evaluate the utility of the simplified and reformatted flight data. Results of this evaluation will guide the planning of subsequent tests in which the realism of the test situation will be increased by provision of control input capabilities.

The ultimate objective of the CCIL tests will be to determine the minimum requirements for flight data display, including the selection of what is to be displayed, how it is to be patterned, the required size, brightness, contrast,

etc., of display, and the controller input facilities that will provide adequate performance. It is anticipated that the questions of data simplification, formats, and physical display characteristics will be resolved first. Once the required minimum display can be described with a degree of certitude, principal attention will shift to the requirements for improved input systems. While conventional NAS inputs will be installed first (ANK and QAK), it is not thought likely that these buttonpushing systems will prove to be the best means for the controller to use in calling up needed information, revising the display, and superimposing control information. In addition to the economic savings in paper and mechanical device upkeep, one of the principal goals of automation in this field is to relieve the human operator of the need to do the routine clerical work, such as updating and resequencing, that can be done by the computer. It is evident that this reduction in controller workload must not be paid for by requiring the controller to push a lot of buttons. It is probable that one of the chief reasons that the paper flight strip has so long remained a part of the system is the very ease and naturalness of use, the ready way that the controller can reach out and write on the paper strip, or simply lift its holder out of the M1-strip-holder board. It would not be an improvement in workload to exchange an improved display for a requirement to type out a message to the computer each time a displayed data item had to be changed. The way to avoid a workload trap of this kind is to provide a system that acts automatically when the required information is already in the processor and that gives the controller an easy and natural means of inserting such additional data as is required. If the ANK is thought of as constituting one end of the input workload continuum, the voice encoder teamed with a touch overlay might be considered the opposite extreme. In between, there are a variety of other input devices such as the data tablet that may be examined.

A voice encoder system is presently under test in the CCIL. This input channel will be evaluated as a means of putting data into the automation system in the same manner that data is passed to the pilot or to other sector controllers. It appears that air traffic control has a conventional vocabulary and syntax, and that individual controllers exhibit a degree of consistency of verbal style. Both of these system properties suggest the feasibility of a voice encoder.

Both hard-wired and acoustic touch-overlay devices are available in the CCIL. Along with the act of speaking, the act of reaching out and touching is high in naturalness and ease of execution. Further, it is a physical act that may be observed by control team members. This allows simultaneous input to the computer and intrateam communication.

The preceding discussion of input techniques is not intended to point to any final design choices, but rather to suggest the need for laboratory tests beyond the matter of what should be displayed and how it should be organized. In addition, there is another major area of system design yet to be broached. That is the matter of display volatility and the means to continue essential control functions in the case of system failures. Some degree of temporary shutdown of the flow of information from the central automation system will be a potential danger in all complex data-processing systems, although the history

of recent system evolution shows that major failures become less and less likely as systems are perfected. There are several possible approaches to operation in a backup mode when an interruption of the main data channel occurs, and these must be evaluated before a final system design can be cast. At the display surface, the last updated presentation can be frozen. In the case of the deformographic technique, the presentation is purported to remain literally for days after the external feed is interrupted. But a frozen display is of limited value in making decisions as time passes. This suggests that the sector inputs should be processed to and from the main automation channel through a local storage and mini-processor that is not dependent on main-channel updates and that can feed selected data to the sector displays. Perhaps such a protected local device could serve a group of sectors, but in any case it seems likely that cost factors would necessitate a reduction in display capacity when operating in the backup mode. This raises the important question of how much display is enough to preserve the essential and safe control capacity. Expected duration and extent of possible automation system outages would be important factors to consider in attempting to answer this question. Also, the meaning of essential control capacity, in terms of permissible delay and inconvenience to the controlled aircraft, requires further definition. The whole subject of what is likely to go wrong and what is the most practical way to protect essential functions will require study and experimental test of the proposed solutions.

CONCLUSIONS AND RECOMMENDATIONS

Based on a field survey of eight enroute centers and the initial planning of a laboratory test and evaluation program, it is concluded that:

1. Controllers experienced with the radar data processing system believe that in a radar data processing environment the information presently carried on flight progress strips can be reduced in a redesigned and improved sector. While a nucleus of data is required for continuous display, other items can be made available on call, and certain other data fields of the present flight strip may be deleted.

2. The record function of the paper flight strip may be replaced by the provision of radio channel recording and automation system input recording. Other essential functions of the controller input of flight data may be accomplished with novel devices that do not impose a heavy buttonpushing workload.

3. In view of the above conclusions, it appears highly probable that as a replacement for paper flight strips, an automated electronic display can be provided.

4. Laboratory experimentation should be conducted to perfect controller input facilities and modified procedures suitable for an improved sector. A further goal of such experimentation should be to examine provisions for a backup mode of operation in case of various levels of outage of the main automation channel.